Non-Contact Biometric Identification and Authentication using Microwave Doppler Sensor

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***Abstract*—As described in this paper, we propose a non-contact biometric authentication method with heartbeat features measured using a microwave Doppler sensor. The heartbeat component is measured as personal characteristic information attributable to individual differences in the myocardium and blood vessels. Biometric authentication using electrocardiogram (ECG) or pulse wave has been proposed in reports of earlier studies, but such methods require direct contact of the sensor with the human skin. However, heartbeat information can be measured and authenticated without contact to the skin when using the proposed method. The microwave Doppler sensor can detect minute vibrations of the body surface caused by heartbeat. The salient difficulty of the microwave Doppler sensor is noise contamination such as that caused by body motion. This study introduces the use of time–frequency analysis with an autoregressive model to reduce the noise influence and emphasize heartbeat features. An ID generation and authentication algorithm using a frequency feature of the heartbeat component is proposed. The proposed method was evaluated using measurements taken of 11 participants. Measurement results show a 92.8% true acceptance rate and a 3.9% equal error rate.**

Keywords—biometric authentication, heartbeat, identification, non-contact, microwave Doppler sensor

I. INTRODUCTION

With the development of information and communication technology in recent years, the importance of security measures is increasing. Personal information protection and personal identification are important technologies for practical applications. Particularly, biometric authentication have attracted attention: it extracts feature quantities from various biometric information and identifies individuals based on the feature. Biometric authentication requires no memorization or password input. Moreover, it is not necessary to carry physical ID information of any kind, therefore reducing the user's burden. Furthermore, there is little risk of stolen passwords by others; "spoofing" is difficult. These facts indicate that the biometric authentication is a sufficiently safe and convenient approach for practical applications.

For biometric authentication, facial features, a fingerprint, an iris, and a vein of the palm have been used. They are also put into practical use. Nevertheless, these authentication methods present both benefits and shortcomings. For example, in face authentication, the risk exists that one can deceive an algorithm by showing a photograph instead of a real face. To enhance security, it is effective to combine diverse biometric authentication methods. For that reason, a new authentication method based on a new measurement principle is required.

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Cardiovascular information related to circulatory organs has attracted attention as biological information that is not used in conventional biometric authentication methods. For example, electrocardiography (ECG) indicates the degree of electrical excitement of the heart and it can reveal individual differences in the QRS component. The QRS component represents the excitement of the ventricle. It is possible to generate the ID by extracting the QRS component features from a certain period of the ECG [1, 2]. Unfortunately, these methods require direct contact of the sensor with the skin surface.

From this study, we propose a non-contact identification and authentication method using a 24-GHz band microwave Doppler sensor (see Fig. 1). It can extract frequency features of minute vibrations of the human body surface caused by pulsation of a heartbeat. Non-contact biometric authentication can also improve usability.

II. NON-CONTACT HEARTBEAT MEASUREMENT AND TIME-FREQUENCY ANALYSIS

In the heart, the natural pacemaker sinus node generates an electric stimulus periodically. It is propagated to the myocardium to cause electrical excitation. First, the ventricle

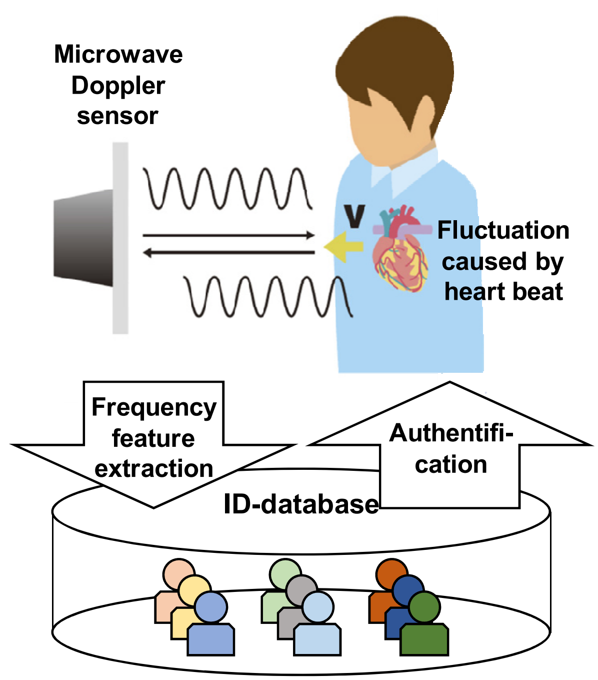

Fig. 1 Contact-less identification and authentication using heart beat information with microwave Doppler sensor.

contracts; then the atrium contracts to deliver blood. Next, blood flows into the atrium and expands it. Finally, blood flows into the ventricle and it expands.

The ECG is a measurement result of changes in body surface potential caused by the electrical stimulation propagated from the heart. In addition, a pulse wave is a measurement result of vibrations of blood vessels caused by blood delivered by pulsation. These signals include individual differences such as the thickness and flexibility of the myocardium, the propagation mode of the electrical stimulation, the elasticity of the blood vessel, and so on.

The microwave Doppler sensor can detect minute vibrations of the body surface caused by a heartbeat without direct skin contact. The objective of this research is to generate IDs equivalent to ECG from Doppler sensor output. For this study, we extract the heartbeat and the feature quantities of individual using time–frequency analysis.

A. Heartbeat measurement using a Microwave Doppler Sensor

When a radio wave is irradiated to an object, its reflected wave has a frequency shifted according to the velocity of the object. This phenomenon is known as the Doppler Effect.

Heartbeat causes minute fluctuations on the body surface. Therefore, they are visible by irradiating microwaves to the body chest because the reflected waves include a frequency shift caused by the Doppler Effect according to the velocity of the chest surface. The heart rate can also be estimated by the time interval of a slight frequency deviation caused by the pulsation. However, because the fluctuation of the chest surface is slight, high temporal resolution and spatial resolution must be used to observe the variation. In this study, a 24-GHz microwave Doppler sensor is used because the higher transmission frequency produces higher resolution.

Letting f_0 [Hz] be the transmission frequency, v [m/s] represent the speed of the irradiation target, and c [m/s] be the speed of light, then using fact that $c \gg v$, from the Doppler effect, the frequency f_1 [Hz] of the reflected wave can be expressed as (1) below.

$$f_1 = \frac{c+v}{c-v} f_0 \approx f_0 + \frac{2v}{c} f_0 \tag{1}$$

Therefore, by mixing the transmitted wave and the reflected wave from the chest, it is possible to extract only the frequency shifted by the Doppler Effect on the body surface. This is called a Doppler wave.

B. Time–Frequency Analysis for Doppler Wave including Heartbeat Components

Because Doppler waves include noise caused by body motion and sensor vibration, it is difficult to detect pulsation on the time axis [3]. For this study, we perform time–frequency analysis to extract feature quantities on the frequency axis to detect the heartbeat characteristics and to perform personal authentication.

The shifted frequency of the Doppler wave caused by the pulsation is several hertz to several tens of hertz. Furthermore, to detect heartbeat information accurately for feature extraction,

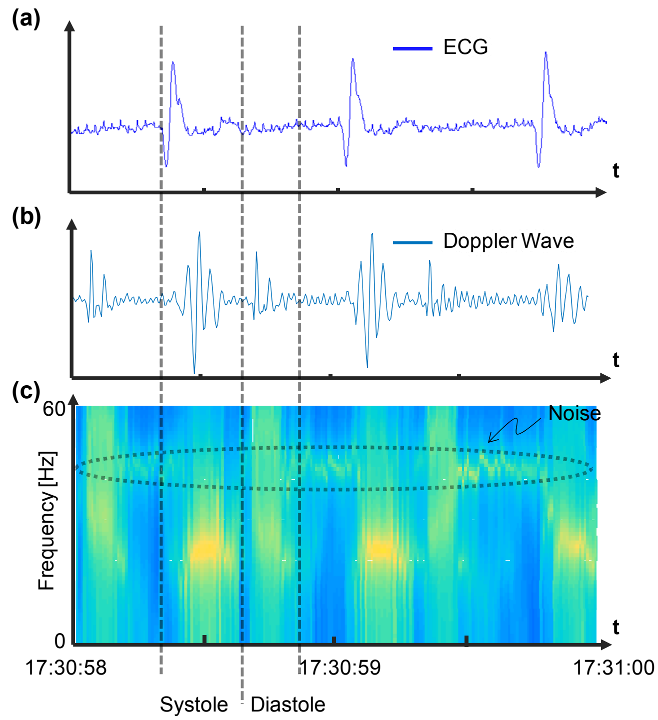

Fig. 2 Measurement example of heartbeats: (a) electrocardiogram (reference sensor), (b) microwave Doppler sensor output, and (c) PSD of Doppler sensor output.

100 ms or better time resolution is necessary because the heartbeat has a short time duration. However, with FFT that is generally used in heart rate variability analysis, it is difficult to observe heart rate components having a window length of 100 ms. Therefore, we introduce an autoregressive (AR) model-based frequency analysis, which is superior for analysis of short time data. In addition, the Burg method is used for parameter estimation of the AR model [4]. Frequency analysis by the Burg method achieves higher frequency resolution than FFT when the window length is short. From the parameters of the AR model, the power spectral density (PSD) is calculated using (2).

$$P(f) = \frac{1}{F_s} \frac{\sigma^2}{\left|1 - \sum_{m=1}^{M} a(m) e^{-j2\pi m f / F_s}\right|} \tag{2}$$

Here, a is an AR coefficient, e stands for white noise, M signifies model order, F_s denotes the sampling frequency, and σ^2 represents the dispersion of white noise e. In this study, order M is set as 5 according to the empirical rule. Also, F_s was set to 200 [Hz].

Fig. 2 presents measurement results of the ECG and Doppler wave, including the heartbeat. Then, a pasted type ECG sensor is used to record the ECG signal simultaneously with a microwave Doppler sensor. Fig. 2(c) shows the PSD calculated from Doppler wave using the AR model-based time–frequency analysis. As results showed, the Doppler wave can measure heartbeat components accurately, including the heart contraction and expansion. The signal appearing in the frequency band of 40–50 Hz is environmental noise.

III. Identification and Authentication Method

This section presents a description of ID generation and authentication method using the time–frequency analysis results for Doppler waves. Fig. 3 presents the processing flow.

A. ID Generation from Doppler Wave

First, the heartbeat components are identified from PSD. By averaging the PSD power from 0 Hz to 60 Hz at regular time intervals, a bimodal peak appears in the heartbeat component as presented in Fig. 2. That peak represents the contraction and expansion of the heart. For the proposed method, the first peak is used as a reference. Then, a period of 0.2 s before and 0.4 s after the peak is selected as a template. Template matching is conducted using this template to detect all heartbeats from the extraction target period of PSD. In template matching, the residual sum of squares (RSS) is used to detect the heartbeat. PSDs of the same length as the template are extracted from all detected heartbeats. Their average is used as ID.

Next, 0.1 s from the beginning of the ID is divided at intervals of 10 ms, and they are averaged. The obtained 10 ms PSD is subtracted from the entire ID, thereby canceling the environmental noise.

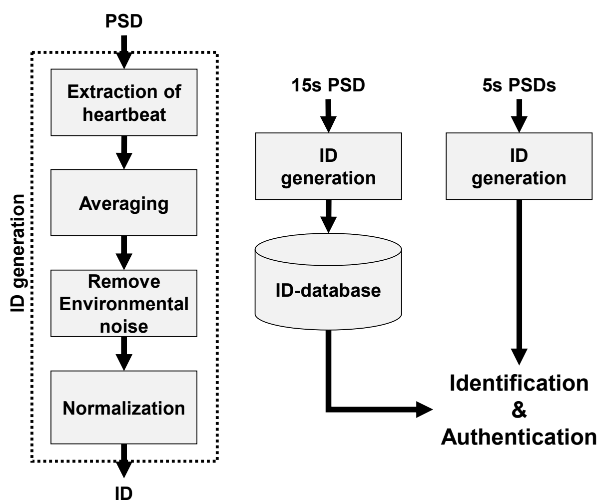

Fig. 3 Flow chart of the proposed ID generation and authentication.

Finally, the average and variance of the powers of all the frequencies included in the ID are calculated. To normalize the ID, this average value is subtracted for all frequencies at all times. Then it is divided by the variance.

B. Authentication

Doppler waves of 15 s per user are measured. Then IDs are generated and registered in the database using the method described above. For authentication, the ID is generated in the same way using a 5 s waveform. Both IDs are 0.6 s PSD, including the heartbeat. In authentication, the ID is divided every 10 ms. The RSS of each frequency at each time is calculated as shown below.

$$R = \sum_{f=1}^{m} \sum_{t=1}^{n} (x(f,t) - y(f,t))^2. \quad \textbf{(3)}$$

In that equation, $x_i(f,t)$ and $y_i(f,t)$ respectively represent the power of PSD included in the two IDs. m and n represent the number of data as m = 60 [Hz] / 1 [Hz] = 60 and n = 0.6 [s] / 10 [ms] = 60. The smaller R represents stronger correlation between IDs. Next we examine the accuracy of authentication using threshold against R.

IV. Performance Evaluation

To evaluate the performance of the proposed method, we measured 11 participants: 9 men and 2 women who were 22–36 years old. To suppress the influence of environmental noise, measurements were conducted with the Doppler sensor in proximity to the outside of the garment of the participant. IDs for database registration were generated from Doppler waves of 15 s for all participants. Then authentication evaluation was performed with the Doppler wave divided every 5 s. Fig. 4 shows the generated IDs of 11 people.

Table I presents the results of evaluating the identification accuracy for this database. Because the evaluation is performed by selecting a segment with the least influence of noise from the measurement data of 100 s, the number of IDs tested for each participant differs. For data measured simultaneously, the

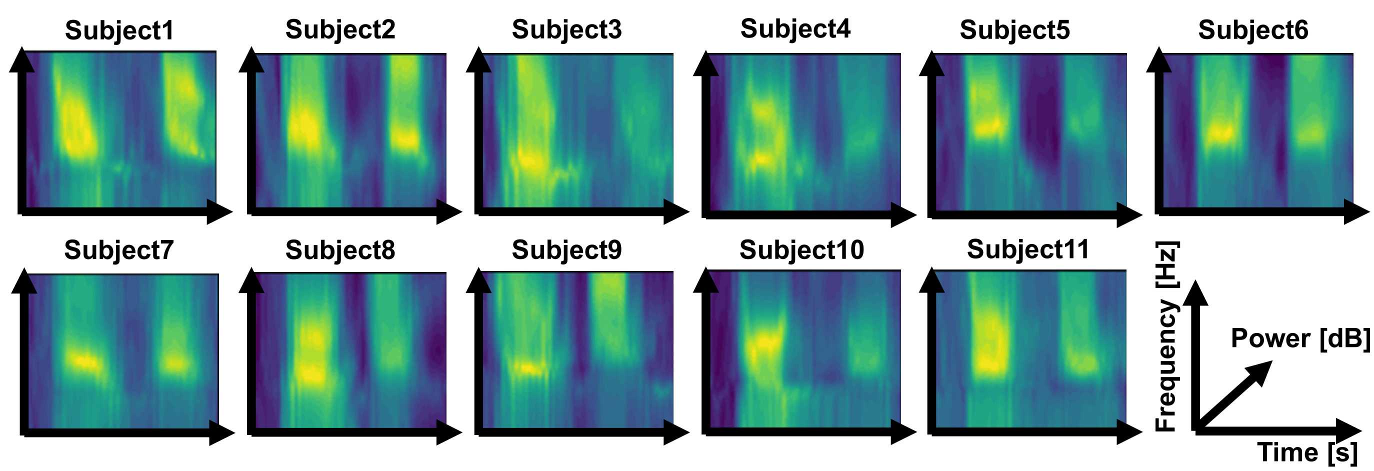

Fig. 4 Generated ID using the proposed method from 15 s Doppler wave PSD of 11 participants.

true acceptance rate (TAR) was 92.80% on average. Participants with TAR of 90% or less are affected by SNR deterioration because of body motion artifacts.

Next, we took measurements of two participants again after 5 months. During measurement, the participants were sitting in a resting state to reduce body motion. No significant difference was found in the recognition rate over time, although the difficulty of precision deterioration caused by body motion has not been resolved.

Finally, the evaluation results of false acceptance rate (FAR) and false rejection rate (FRR) are presented in Fig. 5. These indices are widely used to evaluate authentication. To exclude the influence of body motion artifacts from the result of Table I, evaluation was conducted excluding data with a large RSS value. The equal error rate (EER) when FRR and FAR are equal is 3.9%.

FRR, TAR, and EER obtained using the proposed method were comparable with those of earlier studies using ECG (e.g., FRR of 1.9% [2], TAR of 81.82% [5], and EER of 4.61% [6]).

TABLE I IDENTIFICATION RESULTS

Subject	Date	# of test IDs	TAR [%]
1	Jan. 2017	17	100.00
2	Jan. 2017	18	100.00
3	Jan. 2017	16	93.75
4	Jan. 2017	18	94.44
5	Jan. 2017	19	89.47
6	Jan. 2017	19	89.47
7	Jan. 2017	15	100.00
8	Jan. 2017	14	100.00
9	Jan. 2017	16	81.25
10	Jan. 2017	15	86.67
11	Jan. 2017	14	85.71
Avg.			92.80
8	Jun. 2017	20	90.00
9	Jun. 2017	19	84.21
Avg.			87.11

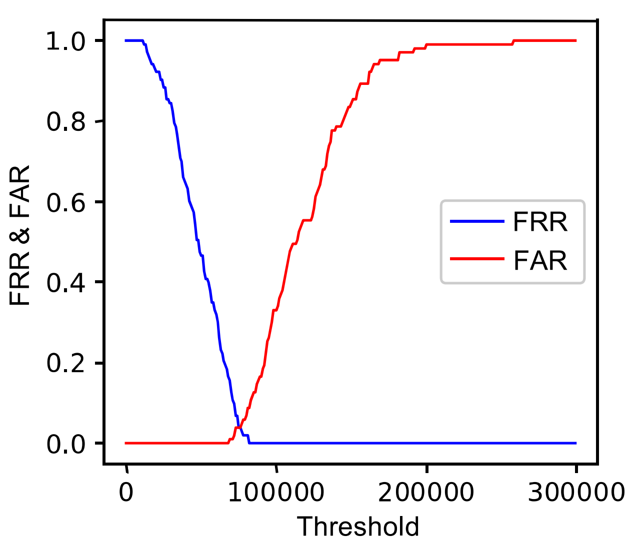

Fig. 5 FRR and FAR of 11 participants.

V. Discussion and Conclusion

As described in this paper, we examined our non-contact biometric authentication method using a microwave Doppler sensor. We proposed the ID generation method using time–frequency analysis for Doppler waves. Evaluation results demonstrated the possibility of identifying and certifying individuals as with the ECG-based methods.

For this study, an ID was generated using 15 s Doppler waves and registered in the database. The ID for authentication was generated using 5 s Doppler waves. Because this time duration is determined by a tradeoff between usability and performance, investigating its influence on performance is necessary.

The evaluation result indicates that authentication can be performed even after several months. However, when the positional relation between the sensor and the human body changes, or when the heart rate greatly fluctuates, the possibility exists that the frequency characteristic and the interval of the expansion and contraction are changed. This point must be investigated in future studies.

Furthermore, using the proposed method, environmental noise is removed at ID generation, but body motion artifacts cannot be removed completely. Although their influence is reduced through averaging, in general, the body movement noise is larger than the heartbeat component. Therefore, it cannot be removed sufficiently by averaging over 5 s. In the evaluation, those with the minimum value of the correlation coefficient with the ID of the database larger than a certain value were excluded as noise. However, this criterion requires human examination. We expect to examine the reduction of body motion artifact and the influence of the health condition of the participants in future studies.

References

[1] P. Sasikala and R. S. D. Wahidabanu, "Identification of Individuals using Electrocardiogram," *Int. J. of Computer Science and Network Security*, vol. 10, no. 12, pp. 147–153, Dec. 2010.

[2] Shin Jae Kang, Seung Yong Lee, Hyo Il Cho, and Hyunggon Park, Senior Member, IEEE, "ECG Authentication System Design Based on Signal Analysis in Mobile and Wearable Devices," *IEEE Signal Processing Letters*, vol. 23, no. 6, pp. 805–808, June 2016.

[3] D. Matsunaga, et al., "Non-contact Instantaneous Heart Rate Monitoring Using Microwave Doppler Sensor and Time-Frequency Domain Analysis," *Proc. of IEEE BIBE*, Taichung, Oct. 2016, pp. 172–175.

[4] K. Vos, "A Fast Implementation of Burg`s Method," www.opus-codec.org/docs/vos_fastburg.pdf, Aug. 2013.

[5] Juan Sebastian Arteaga-Falconi, Hussein Al Osman, and Abdulmotaleb El Saddik, "ECG Authentication for Mobile Devices," *IEEE Transactions on Instrumentation and Measurement*, vol. 65, pp. 591–600, Mar. 2016.

[6] Hyun-Soo Choi, Byunghan Lee, Sungroh Yoon, "Biometric Authentication Using Noisy Electrocardiograms Acquired by Mobile Sensors," *IEEE Access,* vol. 4, pp. 1266–1273, Mar. 2016.